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Grid-connected isolated PV microinverters: A review

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ABSTRACT

Galvanic isolation in grid-connected photovoltaic (PV) microinverters is a very important feature concerning power quality and safety issues. However, high-frequency transformers and high switching losses degrade the efficiency of the isolated types of microinverters. Recently, several isolated topologies were proposed to increase the efficiency and lifetime of PV converters. This paper presents a comprehensive review of the most recent isolated topologies of PV microinverters. These topologies are categorized into two groups in terms of their power processing stages: 1) single-stage microinverter and 2) multi-stage microinverter. Various topologies are presented, compared, and scrutinized in terms of the power losses at different stages, control techniques, position of the decoupling capacitor, and cost analysis. Recommendations are provided to improve the existing topologies and select the suitable control techniques to obtain a clear picture of the framework for next-generation isolated PV microinverters.

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1. Introduction

According to the International Energy Agency (IEA) 2012 analysis, approximately 1.3 billion people (19% of the global population) lived without access to electricity in 2010, a number that is expected to decline to about 1 billion people (12% of the global population) by 2030 [1]. Renewable energy has become economically competitive with conventional fuels in the past five years, and the IEA says that 60% of new connections will need to come from decentralized micro-grids and off-grid installations, such as solar home systems [2]. The shortcomings of renewable energy sources with unpredictable output can be mitigated by adopting energy storage techniques [3–5]. To control the emissions of toxic gases and metals from fossil-fuel steam electric generators, the generation capacity of clean and non-toxic renewable energies must be extended. The U.S. Annual Energy Outlook 2014 (AEO, 2014) estimated that the total renewable generating capacity will grow by 52% from 2012 to 2040 in the United States alone, with solar power leading the growth in renewable capacity by increasing from less than 8 GW in 2012 to more than 48 GW in 2040 [6]. The German *Energiewende* aims to generate at least 35% of its electricity from green sources by 2020 and is expected to surpass 80% (approximately 488 billion kWh per year) by 2050 [4].

Among the renewable energy sources, photovoltaic (PV) energy is considered one of the most promising emerging technologies. Based on the roadmap envisioned by the IEA, PV's share of global electricity will rise to 16% by 2050. In the last six years, the cost of full PV systems has decreased to one-third with a reduction of 80% cost of the PV modules because of mass production [7]. Given the natural abundance of crystalline silicon semiconductor materials, 90% of the world's total PV cell production are based on silicon technology at an average cost of 0.10 USD/kWh and have conversion efficiencies in the range of 17–25% [8]. Next-generation nanostructured solar cells are expected to reduce the cost to 0.03 USD/kWh with a 33% maximum conversion efficiency [9,10]. In addition, low-cost perovskite solar cells will cause PV technology to proliferate more rapidly in the near future [11–13].

PV systems connected with the AC grid are more cost effective and require less maintenance than standalone systems because they do not need batteries for storage purposes. Li-ion or lead-acid battery storage is commonly used in standalone systems, which increases overall cost and requires additional control for charging and discharging [14–16]. Therefore, grid-connected PV systems occupy 99% of the total installed capacity compared to 1% of the standalone systems [17]. The performances of grid-connected PV systems are investigated and analyzed in [18–20]. Power inverter is one of the key components for injecting PV power into the AC grid. Grid-connected PV systems can range from a single PV module of around 100 W to more than millions of modules for PV plants of 290 MW [21].

On the basis of the different arrangements of PV modules, the grid-connected PV inverter can be categorized into central inverters, string inverters, multistring inverters, and AC-module inverters or microinverters [22]. The microinverter or module-integrated converter is a low power rating converter of 150–400 W in which a dedicated grid-tied inverter is used for each PV module of the system. The compact design attached to the back of each PV module with the highest maximum power point tracking (MPPT) accuracy and the provision for further integration of PV modules introduce an opportunity to realize a true plug-and-play solar AC PV generation. The AC-module inverters require an additional DC–DC stage to boost the voltage with respect to the grid level because of the low voltage rating of PV modules (typically <60 V DC). The additional DC–DC stage is usually used with a high-frequency compact transformer that provides the galvanic isolation and improves the safety issue without using line-frequency bulky transformer in the AC grid side. Line frequency transformers are only applicable in case of a single-stage centralized PV inverter to increase the inverter voltage to grid level [23–25]. Non-isolated boost converters or transformerless topologies are also used in the DC–DC stage because of their higher efficiency, increased compactness, and lower cost compared with isolated topologies [26–30]. However, the presence of leakage ground currents, the requirement of dual grounding, and the low voltage gain make transformerless topologies inefficient with respect to isolated topologies.

The main technical challenges for isolated PV microinverters are to achieve high conversion efficiency, low manufacturing cost, and long lifespan. Given that isolated microinverters contain high-frequency transformers, core losses and switching losses are the major concerns to attaining improved efficiency. To achieve a reliable integrated unit with each PV panel, having a compact and long-lifespan microinverter is desired. Researchers have explored various ways to improve microinverter performance. The current study starts with the specified standards set by the utility grid authorities and the performance requirements for PV converters. Next, the evolution of today's microinverters from the beginning of the grid-tied inverter is described in brief. This discussion is followed by a critical review of the performance of the topologies and control arrangements of some existing grid-connected isolated microinverters. Microinverters are mainly classified by single-stage and multi-stage topologies. In single-stage topologies, the flyback converter is commonly used associating an unfolder circuit with a lower number of power semiconductor devices. In multi-